

LA-UR-14-25081

Approved for public release; distribution is unlimited.

Title: Supernova Neutral Current Signal in ^{40}Ar

Author(s): Hayes-Sterbenz, Anna C.
Ibeling, Duligur
Friar, James Lewis

Intended for: CAPTAIN Collaboration Meeting, 2014-07-08/2014-07-09 (Santa Fe, New Mexico, United States)

Issued: 2014-07-09

Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Supernova Neutral Current Signal in ^{40}Ar

Anna Hayes, Jim Friar, Duligur Ibeling, Patrick Jaffke,
Gerry Garvey, and George Fuller
Funding through LDRD (C. Mauger)

CAPTAIN MEETING, Santa Fe, July 2014

Abstract

We present calculations for the expected supernovae neutrino signals in a liquid argon neutrino detector. We compare these to the signals expected on carbon. In general, to extract the SN physics more than one signals is needed.

At Supernova Neutrino Energies $E_\nu \sim 0-50$ MeV GT Transitions Dominate

$$\sigma_\nu = \frac{G_F^2 g_A^2}{\pi} \left\langle f \left\| \vec{\Sigma}(q) \right\| i \right\rangle^2, \quad \vec{\Sigma} = \vec{\sigma} \vec{\tau}$$

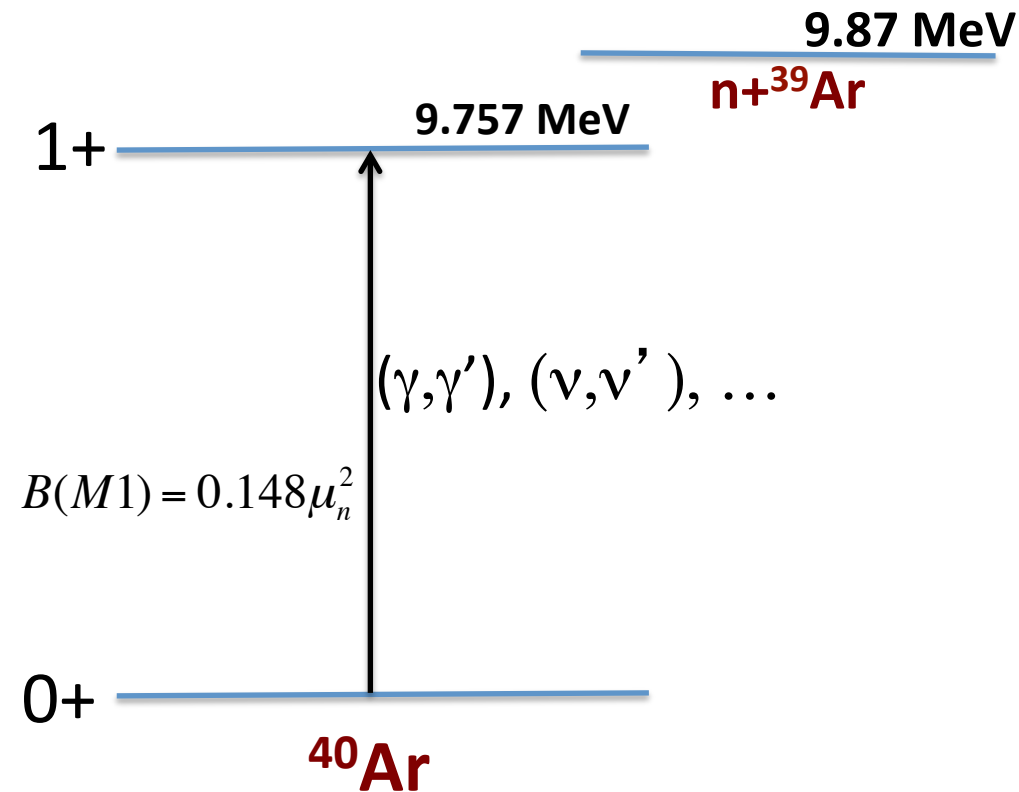
$$\xrightarrow{q=0} \frac{G_F^2 g_A^2}{\pi} B(GT)$$

B(GT) can be approximated by the B(M1) gamma-ray strength, if the γ -transition is almost pure spin-flip

$$B(GT) = \frac{1}{2} \langle \sigma \tau \rangle^2$$

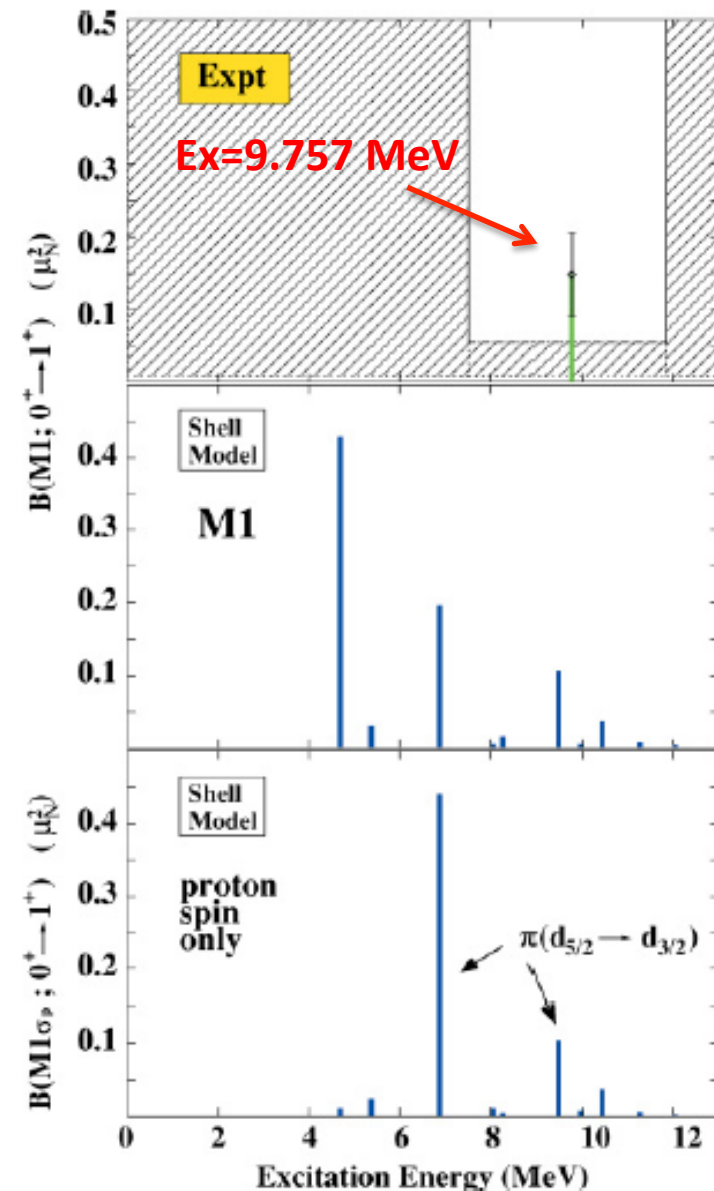
$$B(M1) = \frac{3}{4\pi} \left\{ g_l^{IS} \langle \ell \rangle + \frac{g_s^{is}}{2} \langle \sigma \rangle + \frac{g_s^{IV}}{2} \langle \ell \tau \rangle + \frac{g_s^{IV}}{2} \langle \sigma \tau \rangle \right\}^2 \mu_n^2$$

Almost Pure Spin-flip M1 State in ^{40}Ar at 9.757 MeV



$$B(M1) = 0.148 \mu_n^2,$$

and pure $d_{5/2} \rightarrow d_{3/2}$ proton spin-flip
 $\Rightarrow B(GT) = 0.0418$



1. Q-dependence of the form factors lowers cross section
2. Weak magnetism gives a ~20% difference between ν & $\bar{\nu}$

Four operators determine the neutral cross section to the 9.757 MeV 1^+ in ^{40}Ar

$$T_{J=1M}^{mag} = \frac{q}{M_n} \left[F_1^V \Delta_{J=1}(q) - \frac{1}{2} \mu^V \Sigma'_{J=1}(q) \right]$$

$$M_{J=1}^5 = \frac{q}{M_n} \left[F_A \Omega_{J=1}(q) - \frac{1}{2} (F_A - \omega F_p) \Sigma''_{J=1}(q) \right]$$

$$L_{J=1}^5 = \left[F_A - \frac{1}{2} \left(\frac{q}{M_N} \right)^2 M_N F_p \right] \Sigma''_{J=1}(q)$$

$$T_{J=1}^{el5} = F_A \Sigma'_{J=1}(q)$$

$$\langle d_{3/2} \| \Delta \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}} \sqrt{10} \frac{1}{5} \left(1 - \frac{2}{5} y \right) \exp(-y)$$

$$\langle d_{3/2} \| \Sigma' \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}} \sqrt{10} \frac{4}{5} \left(1 - \frac{11}{10} y + \frac{1}{5} y \right) \exp(-y)$$

$$\langle d_{3/2} \| \Sigma'' \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}} \sqrt{5} \frac{4}{5} \left(1 - \frac{9}{5} y + \frac{2}{5} y^2 \right) \exp(-y)$$

$$\langle d_{3/2} \| \Omega' \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}} \sqrt{5} \left(1 - \frac{2}{5} y \right) \exp(-y)$$

$$y = (bq / 2)^2$$

=> At $E_\nu \sim 25$ MeV cross section drops below the simple $\frac{G_F^2 g_A^2}{\pi} B(GT)$

2. Weak magnetism gives a ~20% difference between ν & $\bar{\nu}$

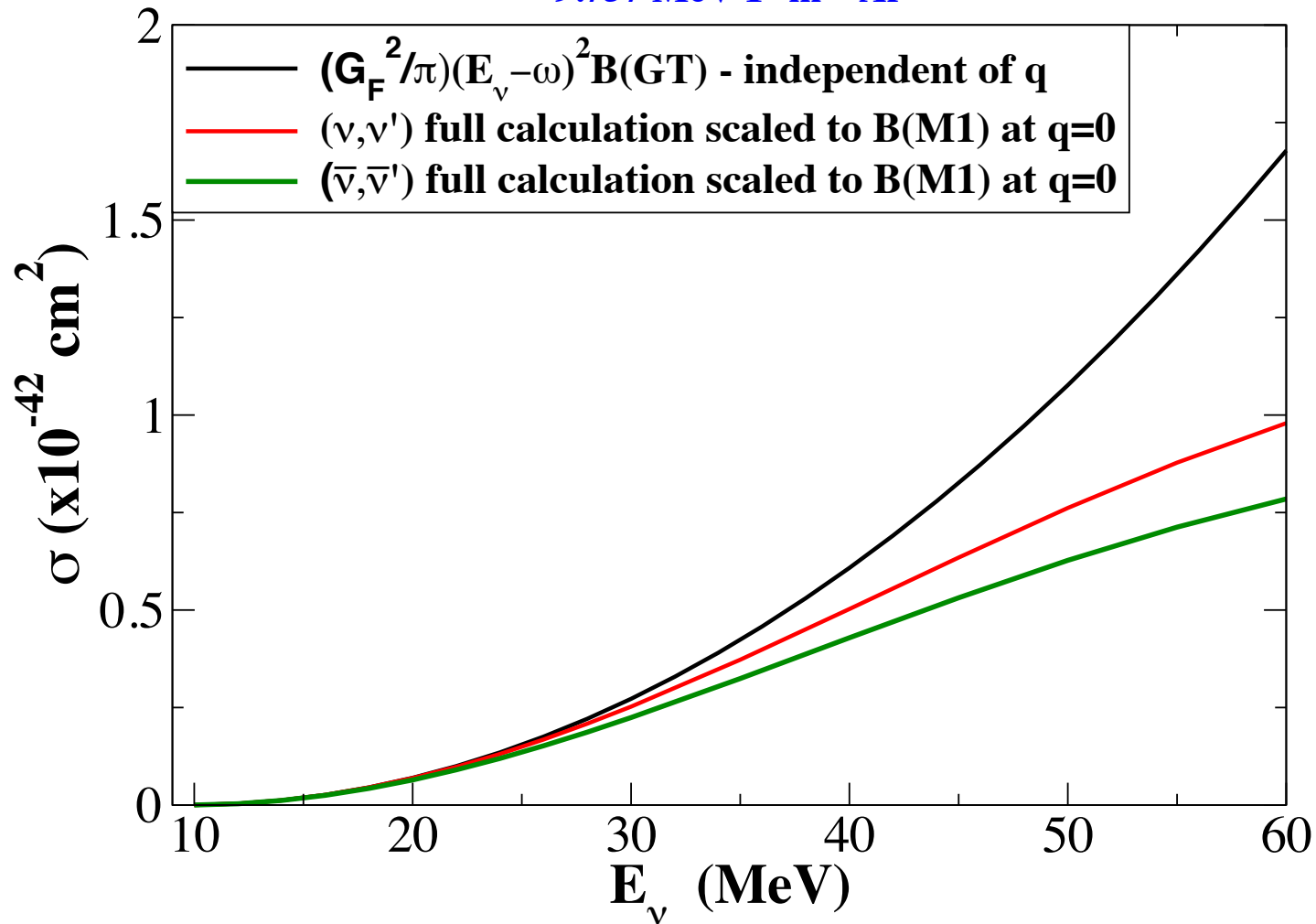
Interference term has opposite sign for neutrino versus antineutrino

$$\sim \pm T_V^{mag}(q) T_A^{el}(q)$$

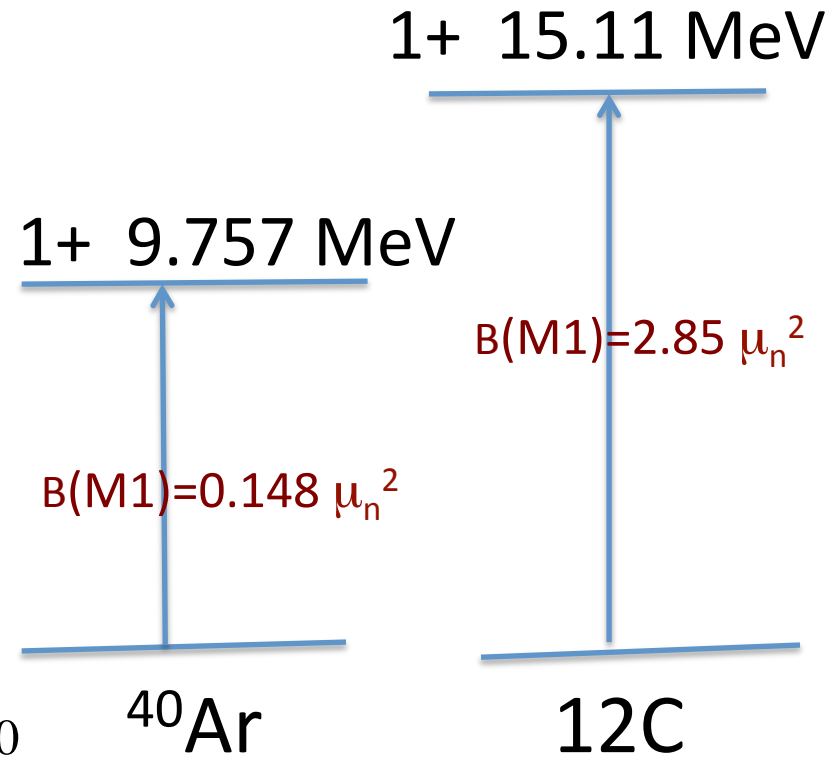
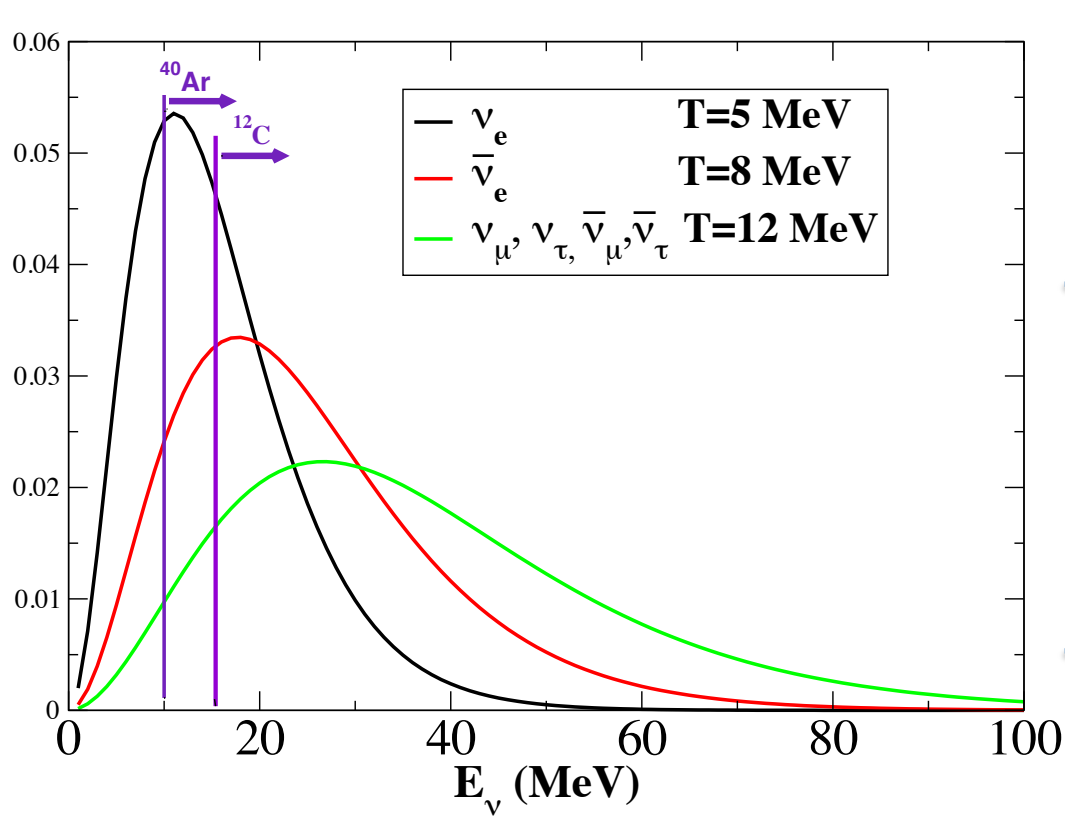
=> Neutrino and anti-neutrino cross sections deviate at $E_\nu \sim 25 \text{ MeV}$

Predicted Cross Sections

Neutral current cross section
9.757 MeV 1^+ in ^{40}Ar



Fermi-Dirac Neutrino Flux – No Oscillations

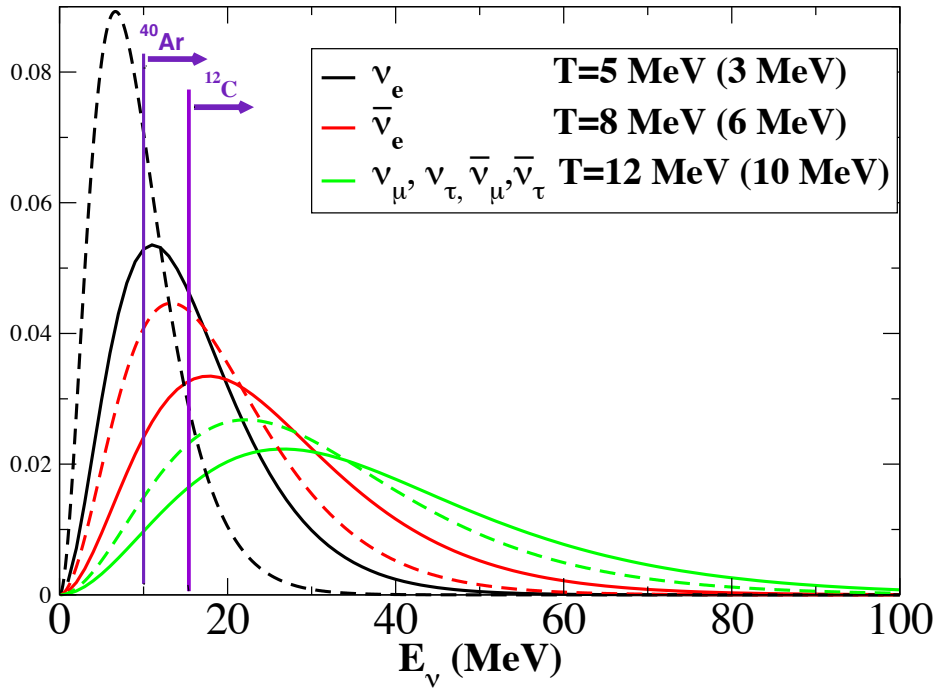


Total Cross section (all 6 neutrinos flavors)

$$^{40}\text{Ar} \ 1.1 \times 10^{-42} \text{ cm}^2 \quad \langle E_\nu \rangle = 44 \text{ MeV}$$

$$^{12}\text{C} \ 16.0 \times 10^{-42} \text{ cm}^2 \quad \langle E_\nu \rangle = 48.8 \text{ MeV}$$

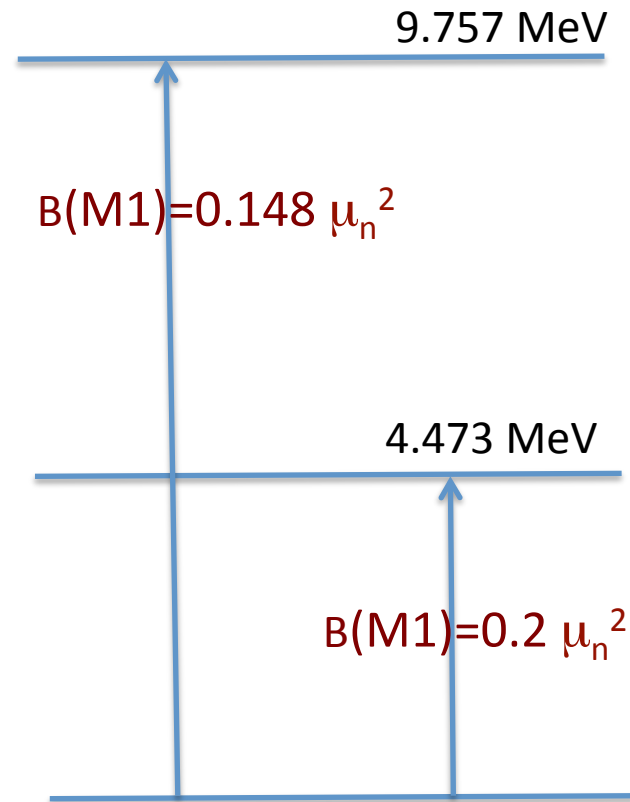
SN Neutrino Temperature Uncertain



ν_e 3-15% - also measured via CC

	$\sigma^{40\text{Ar}} \times 10^{-42} \text{ cm}^2$		$\langle E\nu \rangle \text{ MeV}$		$\sigma^{12\text{C}} \times 10^{-42} \text{ cm}^2$		$\langle E\nu \rangle \text{ MeV}$	
	$T>$	$T<$	$T>$	$T<$	$T>$	$T<$	$T>$	$T<$
ν_e	.07	.01	30	22	.6	0.05	35	26.
$\nu_{e\text{-bar}}$	.18	.1	41	34	2.4	1.0	46	38
$\nu_{\mu,\tau\text{-bar}}$	.37	.34	53	49	5.8	4.1	57	52
$\nu_{\mu,\tau}$	.45	.3	52	48	7.3	5.0	58.	53

Additional Neutral Current Signal in ^{40}Ar at 4.473 MeV



9.757 MeV state almost pure $d_{5/2} \rightarrow d_{3/2}$
 $\Rightarrow (\nu, \nu)$ cross section straightforward

4.473 MeV structure unknown

- Needs more work
- Emitted gamma-ray could confuse (ν_e, e^-) signal

To be done

- Neutral current signals of different SN temperatures, etc.
- Charged current cross sections (including q -dependent form factors) and signatures
- Breakup of nucleus with neutron emission
- Analysis of signals in different detectors, water Cherenkov, etc. to max extraction of SN physics